REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)

2. REPORT DATE

3. REPORT TYPE AND DATES COVERED
Technical Report

4. TITLE AND SUBTITLE
Physiological, Biomechanical, and Maximal Performance Comparisons of Soldiers Carrying Loads Using U.S. Marine Corps Modular Lightweight Load-Carrying Equipment (MOLLE), and U.S. Army Modular Load System (MLS) Prototypes

5. FUNDING NUMBERS

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Military Performance Division
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8. PERFORMING ORGANIZATION REPORT NUMBER
T99-4

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Medical Research and Materiel Command
Fort Detrick, MD 21702-5012

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)
Tests on eleven male soldiers carrying "fighting", "approach", and "sustainment" loads showed that prototype U.S. Marine Corps Modular Lightweight Load-Carrying Equipment (MOLLE), and prototype U.S. Army Modular Load System (MLS) did not differ as to: energy cost or maximal speed of load-carriage; the speed at which a walking soldier could get prone and return to a standing position; the speed at which a walking soldier could get prone, roll three times and aim the weapon; peak and average ground reaction braking force; knee range of motion; or effect on marksmanship. The MOLLE bested the MLS in: the operability of its quick-release mechanism; shoulder, hip and total-body comfort; maintenance of upright walking posture; minimization of front-back trunk sway and vertical bobbing; minimization of lateral foot forces; and subjective ratings by soldiers. The MLS bested the MOLLE in: minimization of heel-strike and toe push-off forces; speed on the obstacle course; effect on grenade throwing; and average shoulder strap pressure. Though superior, the MOLLE's quick-release system could be easier to find and reach. With both the MOLLE and MLS, when body armor was worn, the waist-belt could not be cinched tightly enough to transfer much weight from the shoulders to the hips. The Interceptor armor used with the MOLLE was particularly loose around the waist. A durability problem with the test MOLLE pack frames appears to have been solved by improved, full-production manufacturing methods.

14. SUBJECT TERMS
load carriage, backpack, march, MOLLE, MLS, modular, energy cost, speed, biomechanics, physical performance, marksmanship, posture, obstacle course, grenade throw, pressure, body armor

15. NUMBER OF PAGES
50

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

U.S. ARMY RESEARCH INSTITUTE OF ENVIRONMENTAL MEDICINE

TECHNICAL REPORT NO. T99-4
DATE February 1999
AD A360524

19990405 024

PHYSIOLOGICAL, BIOMECHANICAL, AND MAXIMAL PERFORMANCE COMPARISONS OF SOLDIERS CARRYING LOADS USING U.S. MARINE CORPS MODULAR LIGHTWEIGHT LOAD-CARRYING EQUIPMENT (MOLLE), AND U.S. ARMY MODULAR LOAD SYSTEM (MLS) PROTOTYPES

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U.S. ARMY MEDICAL RESEARCH AND MATERIEL COMMAND

Physiological, biomechanical, and maximal performance comparisons of soldiers carrying loads using U.S. Marine Corps Modular Lightweight Load-Carrying Equipment (MOLLE), and U.S. Army Modular Load System (MLS) prototypes

Physiological, biomechanical, and maximal performance comparisons of soldiers carrying loads using U.S. Marine Corps Modular Lightweight Load-Carrying Equipment (MOLLE), and U.S. Army Modular Load System (MLS)

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BACKGROUND

In 1994, the U.S. Army and U.S. Marine Corps conducted front-end-analyses (FEAs) on individual load-carrying equipment and individual body armor. The purpose of the FEAs was to conduct a comprehensive evaluation of overall requirements of the Army and Marines, and determine where current technology could lead in design and performance. Upon completion of the FEAs, the U.S. Army Infantry Center wrote an operational requirements document for modular body armor (MBA) and a modular load system (MLS). The acquisition strategy specified by the Project Manager-Soldier (PM-Soldier) was to solicit a contract for the design and production of MBA and MLS as an integrated system. The Marines' Program Manager-Combat Support and Logistics Equipment wanted to field body armor and load-carriage equipment more rapidly than the MBA/MLS schedule specified and therefore conducted a separate development program with a government design for body armor and load-carriage equipment. In an effort to minimize duplication of development costs and gain economy of scale, the Army and Marines decided to test each other's MBA/MLS prototypes in order to determine which system should be further developed for use by both services. The study described herein was funded through the U.S. Army Soldier Systems Command (USASSCOM) to compare the prototype load-carriage systems' effects on soldiers' physiological, biomechanical, and maximal performance responses to carrying light, medium, and heavy loads.

ACKNOWLEDGMENTS

The authors would like to thank Michael LaFiandra, Patricia Foster, and Ty Smith for collecting and processing data.

LIST OF SYMBOLS, ABBREVIATIONS AND ACRONYMS

ADL	Arthur D. Little Inc.
ALICE	All-purpose lightweight individual load-carrying equipment
BDU	Battle dress uniform
DCM	Average distance from center of mass of the target (marksmanship test)
FEA	Front end analysis
LED	Light emitting diode
MBA	Modular body armor
MLS	The prototype modular load system designed and produced by ADL and The North Face and tested in the experiment described herein
MOLLE	Modular lightweight load-carrying equipment designed by the U.S. Army Soldier Systems Command, manufactured by Specialty Plastics Products, and tested in the experiment described herein
ORD	Operational Requirements Document
psi	Pounds per square inch
SGT	Shot group tightness (marksmanship test)
STIME	Sighting time; the time between LED illumination and trigger pull (marksmanship test)
USANRDEC	U.S. Army Natick Research, Development and Engineering Center
USARIEM	U.S. Army Research Institute of Environmental Medicine
USASSCOM	U.S. Army Soldier Systems Command
% HITS	Target hits as a percentage of total shots (marksmanship test)

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EXECUTIVE SUMMARY

The experiment evaluated the physiological, biomechanical, and maximal performance responses of soldiers carrying light, medium, and heavy loads using the prototype U.S. Marine Corps Modular Lightweight Load-Carrying Equipment (MOLLE), and the prototype U.S. Army Modular Load System (MLS). Eleven male soldiers were tested with each system as they carried "fighting", "approach", and "sustainment" loads. Physiological evaluation determined the rate of oxygen consumption while volunteers walked on a level treadmill at three mph in each load and configuration. Biomechanical evaluations were performed using video cameras, a force platform, and contact pressure sensors, to determine gait and posture, pack stability, pack center of mass, joint reaction forces of the lower extremities, range of motion restrictions, and pack contact pressures under the shoulder straps and in the lumbar region of the waist-belt. Maximal performance evaluations were also done on a variety of typical soldier tasks. Physical discomfort questionnaires were completed, and questionnaires were administered to the participants to solicit user feedback. All testing was performed at USASSCOM in Natick, MA, during the Fall of 1997.

The MOLLE and MLS did not differ as to: energy cost or maximal speed of load-carriage; speed at which a walking soldier could get prone and return to standing; speed at which a walking soldier could get prone, roll three times and aim the weapon; peak and average ground reaction braking force; knee range of motion; or effect on marksmanship. The MOLLE showed advantages over the MLS in: the operability of its quick-release mechanism (the MLS version did not function properly); shoulder, hip and total-body comfort; maintenance of upright walking posture; minimization of front-back trunk sway and vertical bobbing; minimization of lateral foot forces; and subjective ratings by soldiers. The MLS showed advantages over the MOLLE in: minimization of heel-strike and toe push-off forces; speed on the obstacle course (largely attributable to the effect of pack shape on low-crawling and to center of mass location on shimmying along a horizontal pipe); grenade throwing; and average shoulder strap pressure.

Even though it generally proved superior to the MLS, the MOLLE could still be improved. Its quick-release system could be made easier to find and reach. Slipping out of the pack straps still appears to be faster than using the quick-release mechanism. There was a problem of frame cracking with the MOLLE test packs which was attributed to torsion during load-carriage, but the manufacturer asserted that full-production casting methods would eliminate the problem. Greater durability of the MOLLE frame due to improved manufacturing techniques has been demonstrated in field testing conducted subsequent to the experiment described herein.

A problem with both systems was that, when body armor was worn, the waist-belt could not be cinched tightly enough to transfer much weight from the shoulders to the hips. The Interceptor armor used with the MOLLE was particularly loose around the waist, accentuating the problem of tightening the hip belt, and allowing too much load movement when the armor was worn without the pack to keep it in place. Because a majority of combat soldiers are physically fit, the waist of the body armor could likely be made several inches smaller without being too tight.

INTRODUCTION

The All-purpose, Lightweight, Individual, Load-Carrying Equipment (ALICE) was type-classified in 1973 and is still standard-issue load-carriage equipment in both the U.S. Army and Marines. Both services recognized the need for a new load-carriage system that would comprise a fighting vest, body armor, and a modular backpack that could be quickly jettisoned without removing the body armor or fighting load. To this end, the Army funded the MLS/MBA program to develop a prototype Modular Load System, referred to as MLS in this report. The Marines funded the development by USASSCOM of a similar system called the Modular Lightweight Load-Carrying Equipment (MOLLE), used in conjunction with Interceptor Body Armor. Both services recognized the advantages of testing both systems together, including both minimization of duplicated effort and risk reduction. The study described herein was one of several different evaluations undertaken to assist the Army and Marines in determining the effectiveness of these load-carrying systems. The project was funded through USASSCOM to compare the load-carriage systems as to their effects on soldiers' physiological, biomechanical, and maximal performance responses to carrying light, medium, and heavy loads

The loads selected for this study are supported by the U.S. Army field manual on foot travel (2). It states that up to 72 lb may be carried on "prolonged dynamic operations" and that "circumstances could require soldiers to carry loads heavier than 72 lb, such as approach marches through terrain impassable to vehicles or where ground/air transportation resources are not available. These ... loads can be carried easily by well-conditioned soldiers. When the mission demands that soldiers be employed as porters, loads of up to 120 lb can be carried for several days over distances of 20 km a day" and "loads of up to 150 lb are feasible". Soldiers in actual combat operations have often reported carrying loads well in excess of 100 lb.

METHODS

RESEARCH VOLUNTEERS

Eleven male volunteers (six from the U.S. Army 10th Mountain Division, and five from the test volunteer pool at the U.S. Army Natick Research, Development, and Engineering Center [USANRDEC] in Natick, MA) were tested to compare the MOLLE and MLS. Because it would have been too potentially injurious for the volunteers to test a third load-carriage system in all the required configurations, the ALICE system was not tested on this group of volunteers. However, the results of the same tests performed with the ALICE system in another of our studies (unpublished) conducted on a different group of 12 soldiers are presented in this report for comparison purposes. Such comparison must be made with caution because the volunteers for the study in which the ALICE was tested were all active-duty 82nd Airborne combat soldiers in extremely good physical condition who highly valued their state of combat readiness; thus, their performances on maximal tests were generally better than those of the

volunteers of the MOLLE versus MLS study. Table 1 shows some basic information about the group of volunteers.

Table 1. Vital statistics of the volunteers (n=11, all male)

Subject Number	Height (cm)	Body Mass (kg)	Age (years)
1	184.9	93.3	24.0
2	177.4	92.4	33.7
3	179.2	69.8	27.8
4	176.8	75.5	30.6
5	184.2	77.3	21.1
6	179.6	90.0	20.4
7	178.4	96.0	20.4
8	170.8	77.1	25.6
9	182.6	109.8	22.1
10	185.5	83.0	19.1
11	170.8	69.3	18.7
mean±SD	179.1±4.9	84.9±12.0	24.0±4.7

The principal investigator or an assisting investigator briefed all potential research volunteers. Informed consent was obtained from those who chose to volunteer. The volunteers participated in the experiment for approximately five weeks, with one or two test sessions a day lasting between one and three hours each, which included testing, waiting for other volunteers to be tested, and resting between trials. The volunteers were trained and tested in and around the U.S. Army Research Institute of Environmental Medicine (USARIEM) located on the grounds of the USANRDEC.

THE TEST BATTERY

Test Conditions and Loads

The volunteers were tested with three different loads. The "fighting load" consisted of the battle dress uniform (BDU), boots, body armor, kevlar helmet, web belt, load-carriage vest, dummy grenades and ammunition clips, and dummy M-16 rifle. The "approach load" included the fighting load plus 20 lb of weight in a backpack, while the "sustainment load" included the fighting load plus 50 lb of weight in the backpack. The weight in a pack consisted of steel plates held at the pack center-of-volume with foam blocks. Weights of all clothing and equipment carried by the volunteers are indicated in Table 2. The variability in weight carried reflects differences in weight of the two pack and body armor systems, and differences in size among the volunteers. Table 3 summarizes the tests administered.

Table 2. Weights (lb, mean±SD) of everything worn or carried by the volunteers, including clothing and boots

LOAD	MLS	MOLLE
fighting	37.4±4.3	37.8±2.2
approach	65.8±3.1	69.5±4.4
sustainment	94.0±4.5	99.6±2.1

Table 3. The tests administered

		MOLLE			MLS		
Test Procedure	Basic Clothing only	Fighting Load	Approach Load	Sustain Load	Fighting Load	Approach Load	Sustain Load
anthropometry	+						
energy cost		+	+	+	+	+	+
biomechanics		+	+	+	+	+	+
2 mile course		+	+	+	+	+	+
disencumber			+	+		+	+
prone and stand	+	+	+		+	+	
obstacle course		+	+		+	+	
prone and roll	+	+			+		
marksmanship	+	+			+		
grenade throw	+	+			+		

Physiological Testing

Energy Cost. In order to estimate energy consumption, oxygen uptake was measured while the volunteers walked on a level treadmill at 3.0 mph, carrying the fighting, approach, and sustainment loads, using each of the two different load-carriage systems, for a total of six load-carriage conditions. The volunteers had to wear a face-mask or mouthpiece by which their expired air was collected and analyzed. The custom-made oxygen-uptake analysis system incorporated an air-flow meter, oxygen analyzer, carbon-dioxide analyzer, pulse counter, and Hewlett-Packard desktop computer and printer which could determine and print out every 30 seconds the rate of oxygen consumption and ventilation per minute expressed both in absolute terms and relative to the individual's body mass. The walking duration per test speed was about five minutes to allow the volunteer to reach a steady-state oxygen uptake.

Biomechanical Testing

Kinematics and Kinetics. The volunteers walked at three miles per hour across a force platform, within the field of view of six Qualisys cameras (Glastonbury, CT) while carrying the fighting, approach, and sustainment loads using each of two different load-carriage systems for a total of six load-carriage conditions. Biomechanical analysis of the camera data was performed using both Qualisys and custom software.

During the biomechanical testing, volunteers wore the standard Army physical training uniform, consisting of the gray T-shirt and shorts with combat boots. Spherical reflective markers approximately one inch in diameter were affixed to the skin (or boot) using double sided tape. Markers were placed on the right side of the body at the base of the 5th metatarsal, lateral malleolus of the ankle, lateral femoral condyle of the knee, greater trochanter of the hip, acromion process of the shoulder, zygomatic arch of the head, lateral epicondyle of the elbow, and the radial styloid process of the wrist.

An additional marker was placed at the location of the sagittal plane center of mass of the pack in each pack/load configuration. The sagittal plane center of mass location was determined in each pack/load configuration by placing the loaded pack, the vest, and the ballistic protective vest on a lightweight, foam torso dummy and using a standard balance board technique.

Volunteers walked along a level, 15-foot walkway at 3.0 miles/hr paced by a custom-built system that cued the volunteer to the appropriate walking speed with a striped cord moving at 3.0 miles/hr located next to the walkway. The M16A1 mockup was carried at port arms. An electronic timing device insured that volunteers walked across the force plate at 3.0 miles/hr $\pm$ 5%. Trials during which the walking speed was not between 2.85 miles/hr and 3.15 miles/hr were discarded, and the trial was repeated. A video motion analysis system (Qualisys, Glastonbury, CT) using six cameras recorded the body movements of the volunteers in three dimensions as they walked across a force plate (AMTI, Newton, MA) embedded flush with the floor. The sampling frequency of the cameras was 60 Hz. The force plate recorded the ground reaction forces as the volunteer stepped on the plate. The sampling frequency of the force plate was 1,000 Hz. Three walking trials were conducted for each system/load configuration. All six experimental conditions were tested in a single session, with the volunteers resting between trials as needed and having a 15-min rest break after each block of trials.

Under the assumption of bilateral symmetry, segmental movement data for the left side of the body was generated by phase shifting the right side data by 180°. A 12-segment model of the human body was constructed (two feet, two shanks, two thighs, two forearms, two upper-arms, a trunk and a head), and the mass inertial properties of the segments were taken from estimates given by Dempster (1). A custom-written software program performed a standard link segment analysis frame-by-frame for a single stride. The single stride selected for analysis was centered on the point when the

right foot struck the force plate. The stride was defined as that portion of the gait cycle from the point in time at which the right foot crossed in front of the left leg to the point in time at which the right foot next crossed in front of the left leg. The custom program calculated the location of the body center of mass as described by Winter (12) and plotted its coordinates for each frame of video data. The program also determined stride length, stride frequency, and body segment displacements, velocities, and accelerations. Joint reaction forces at the ankle, knee, and hip joints were calculated using inverse dynamics.

The vertical and horizontal distances between the load center of mass and the body center of mass were calculated for each frame during the stride. The mean vertical and horizontal distances over the entire stride were then calculated from the frame-by-frame data for a trial. These mean values are given as the vertical and horizontal distances for that trial.

For each frame of video data, the coordinates of a reference point on the trunk were calculated as the midpoint of a line segment connecting the right and left shoulders. The vertical and horizontal distances between the pack center of mass and the trunk reference point were then calculated for each frame during the stride. The relative motion between the pack and the body in the vertical and horizontal planes was assessed by calculating the standard deviations of the pack-to-trunk reference point vertical and horizontal distances, respectively, over the stride. The standard deviations of the mean vertical and horizontal distances calculated from the frame-by-frame data are given as the relative pack motion for a given trial.

The maximum and minimum trunk, hip, knee, and ankle angles were also determined (Figure 1). The trunk angle was defined as the angle between the trunk segment and the vertical axis. For a subject facing towards the right, the trunk angle is positive measured clockwise from the vertical and negative measured counter-clockwise from the vertical. The hip angle was defined as the angle between the thigh segment and the plane defined by the segment connecting right and left hips with the trunk segment. The knee angle was defined as the angle between the thigh and shank segments, and the ankle angle was defined as the angle between the shank and foot segments.

Due to the fact that the duration of a single stride varied across subjects, it was necessary to normalize the differing time scales to allow for the direct comparison of the timing of events within the gait cycle across subjects. This was accomplished by expressing the time course of all the biomechanical variables as a percentage of the stride cycle.

Pack Contact Pressure. The pressures on the shoulders and hips associated with each system/load configuration were measured by placing Tekscan pressure sensor pads (Tekscan, Boston, MA) under the pack straps and back contact area. The sensors are made of thin, flexible, 10.2 cm x 22.9 cm Mylar with a force transducer for each square centimeter. The pressure sensor sampling frequency was 60 Hz. The

computerized Tekscan analysis system was used to determine the localized skin contact pressures placed on the research volunteer in all six experimental conditions. The video and force plate data collection was synchronized with the Tekscan data collection through the use of a common triggering switch. Pack contact pressures are expressed as both the array average (the mean of all individual sensor values including those which recorded zero pressure for each pad over the entire stride) and as the array maximum (the maximum individual sensor value recorded for each pad over the entire stride).

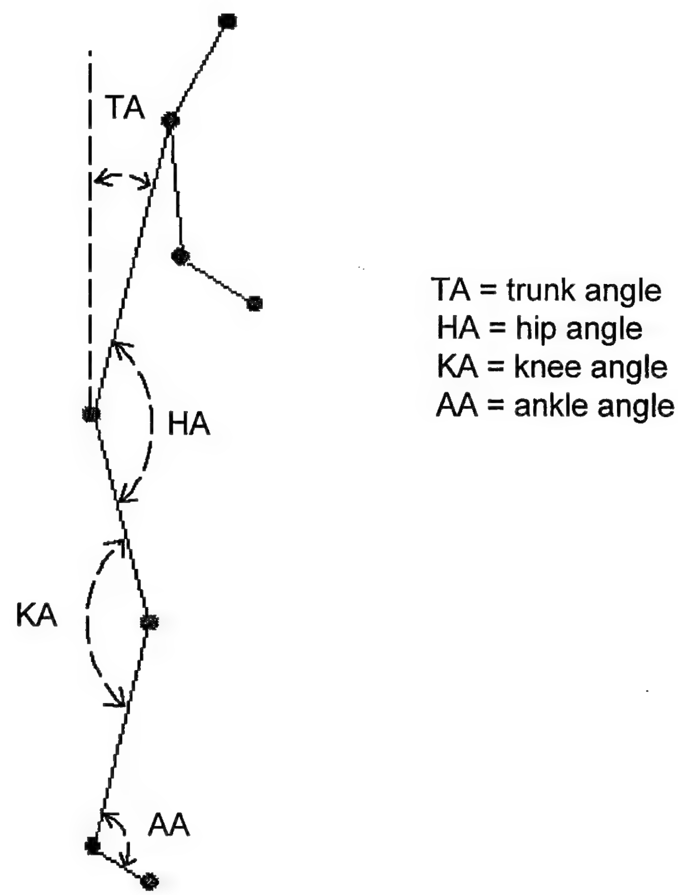

Figure 1. Definition of joint angles.

Anthropometry

In order to determine how body proportions relate to the way in which the pack is carried and to the effectiveness of the backpack frame/waist-belt system, body measurements were made including:

<Circumferences>
waist, hips, thigh, calf
<Diameters>
shoulders, hips, knees, ankles
<Lengths>
trunk, upper leg, lower leg
<Skinfolds>
back, arm, abdomen, thigh

Performance Testing

One of the most critical factors to be considered in evaluating soldier/equipment interaction is the effect of the equipment on the performance of tasks by the soldier in scenarios involving the preparation for and engagement in combat. The tests below were designed to simulate battlefield activities that might be affected by load-carriage system.

Timed Tests. Because the speed with which a soldier can perform a task can greatly affect the outcome of battle, one means of evaluating the soldier/equipment interaction is to time how long it takes the soldier to complete challenging tasks while using the equipment. Thus, the research volunteers were timed on the following tasks while carrying the loads indicated. Before they performed the events, they were trained in proper technique and afforded time to practice, thereby improving consistency and minimizing the risk of injury. Each volunteer

- covered at maximal speed a two-mile paved course which included four small hills. He performed this test while carrying the fighting, approach, and sustainment loads using each of two different load-carriage systems for a total of six load-carriage conditions.

- walked at normal marching speed, and after a verbal signal from the experimenter, completely removed the backpack and attained a prone position on the ground. He performed this test with the approach and sustainment loads using each of two different load-carriage systems for a total of four load-carriage conditions.

- walked at normal marching speed, and after a verbal signal from the experimenter, dropped to a prone position on the ground then stood back up. This test was performed using no pack at all, and under the fighting and

approach loads with each of two different load-carriage systems for a total of five load-carriage conditions.

- walked at normal marching speed, and after a verbal signal from the experimenter, dropped to a prone position on the ground, rolled laterally three full revolutions, and took aim with the rifle. This test was performed with BDU only and with the fighting load using each of the two systems for a total of three conditions.

- negotiated a 6-station obstacle course (Figure 2). This test was performed using no pack at all, and the fighting and approach loads with each of two different load-carriage systems for a total of five load-carriage conditions. The obstacle course included:

- a set of five 18 in high plastic hurdles
- a zigzag of rubber cones, 88 ft long and five ft wide
  - a crawl space of wood/wire, 24" high, 36" wide, and 12 feet long
- a horizontal shimmy pipe, 12 feet long
  - a 54" high sheer wooden wall without footholds or ropes
- a 60 foot straight run

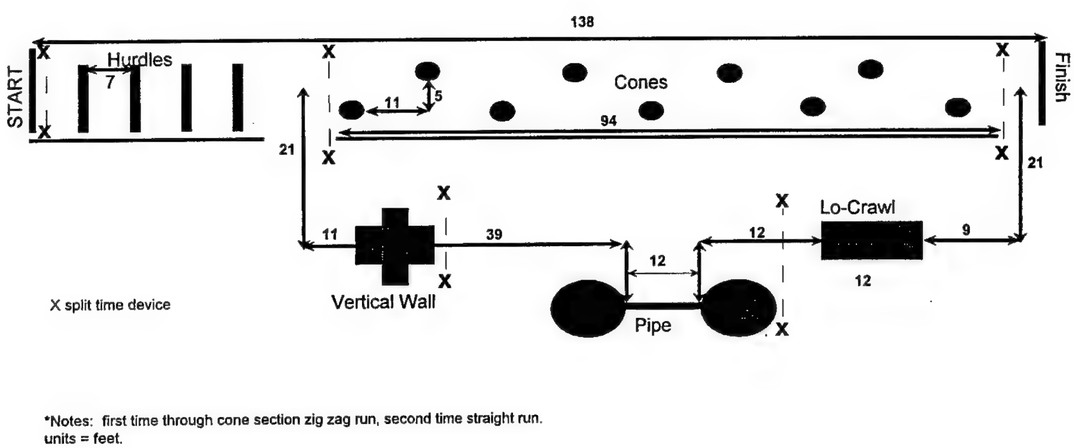

Figure 2. Obstacle course.

Times were obtained for each course segment using a light-beam system with telemetry (Brower Timing Systems, Salt Lake City, UT).

<u>**Grenade Throw**</u>. According to the Soldier's Manual of Common Tasks (3), a soldier should be able to throw a hand grenade to within five m of a selected point 35 m away. Thus, we tested the accuracy with which the volunteers could hit such a target with a dummy hand-grenade, about the same weight (one lb) as a real grenade. Each volunteer threw from a standing position towards a five-meter diameter target 35 m away. Both the number of hits and the distance from the center of the target were recorded. The volunteers were tested in BDU only and with the fighting load using each

of the two systems for a total of three conditions. Five trials were performed for each condition.

Rifle Marksmanship. The rifle marksmanship of the volunteers was tested on a Noptel ST-1000 laser marksmanship simulator (Noptel, Oy; Oulu, Finland). They shot while they wore BDU only and while they wore the fighting load using each of the two load-carriage systems for a total of three conditions. The simulator consists of a laser transmitter, an optical glass laser-sensitive receiver with an associated paper aiming target, a personal computer, manufacturer supplied software, and a disabled M16A1 rifle. The laser transmitter emits a continuous 0.55 mm amplitude 0.8 mm wavelength beam, which is invisible to the eye, that allows aiming positions to be monitored and recorded throughout the sighting and shooting process. A vibration sensor in the laser unit detects when the weapon is dry-fired. Shot location is recorded via the position of the laser on the optical glass laser sensor. The target used was a 2.3 cm diameter circular target located five m from the shooter. This simulated a 46 cm diameter target at 100 m, which is similar to the standard 49 cm wide, "100-m military silhouette man" used on training and qualifying ranges for the U.S. Army. Volunteers were tested for marksmanship speed and accuracy. During assessment, volunteers shot from two positions: the prone unsupported position (i.e. no sandbags or other support except for the ground) and the free-standing unsupported position. Following a verbal "ready" signal and a random 1-10 second preparatory interval, a red LED positioned on the lower left of, and 16 cm from the target was illuminated as the signal to shoot. The volunteer fired at the target as quickly as possible while trying to maintain accuracy. A total of 10 shots or "trials" were taken in each shooting position. Each trial consisted of waiting for the light, sighting the target and pulling the trigger; thus multiple shots were not fired upon a single illumination of the red light. When in the prone position, volunteers were instructed to hold the rifle low enough to enable them to see the stimulus light from above the rifle's sights. In the free-standing unsupported position volunteers were required to hold the barrel of the rifle below the waist while waiting for the stimulus light to come on and then aim and fire the weapon.

Volunteers were tested in the BDU and helmet, and with the two different load-carriage systems for a total of three conditions. Familiarization with the Noptel system was provided prior to actual data collection. All volunteers were experienced marksmen. Familiarization with the laser simulator and the testing procedure consisted of two sessions of a minimum of 30 shots per condition. Some additional training was provided to volunteers whose scores were not consistent. Presentation of conditions was balanced. At the end of the test session, volunteers were also verbally asked "Do you have any comments regarding shooting under these three equipment conditions?" Volunteers' comments were recorded and compiled.

Marksmanship variables were assessed for groups of five shots. These variables included the average distance from center of mass of the target (DCM); shot group tightness (SGT); sighting time (STIME) which was the time from when the red LED light came on to trigger pull; and percentage of targets hit (% HITS). DCM and SGT were calculated, using custom-written software, from the Noptel point and sector scores (10).

Actual values for DCM and SGT can be multiplied by 20 to give simulated full-scaled target measures.

Weather Considerations. There was no threat of heat injury because the testing was conducted in Fall in New England. Upon consultation with Dr. Murray P. Hamlet, authority on cold injury at the USARIEM, it was decided that to avoid possible frostbite, load-carriage trials would be postponed if the ambient temperature were below -2°C (28°F). Because temperatures were relatively mild for winter during the experiment, there were no instances when it was necessary to postpone testing due to the cold.

Comfort

The comfort of the different load-carriage systems was assessed by having the volunteers fill out a "Physical Discomfort Questionnaire" (Appendix A) following each maximal speed two-mile load-carriage run.

ENVIRONMENTAL IMPACT

Testing and training for this study were conducted indoors and outdoors at USARIEM, USANRDEC, and Natick public streets, roads, and recreational land, after securing permission from town authorities. The study involved little or no airborne emission, waterborne effluent, external radiation, outdoor noise, or solid bulk waste disposal, thereby complying with existing federal, state, and local laws and regulations (AR 200-2 Categorical Exclusion A-11).

The field tests and road marches were conducted with six military volunteers from Fort Drum, NY and five military test volunteers from USASSCOM. All volunteers who did not already have off-post housing lived at the existing barracks at USANRDEC. Neither the living arrangements nor the experimental activities had a significant impact on the environment (AR 200-2 Categorical Exclusion A-19). A Record of Environmental Consideration can be found in Appendix B.

RESULTS

ENERGY COST

Table 4 shows that while there were significant differences in energy cost of carrying the fighting, approach, and sustainment loads at three miles per hour on the flat, there was no difference between the cost of carrying the same load using the MLS versus MOLLE. While the results for the ALICE were obtained in another of our experiments on a different group of volunteers (unpublished), it is apparent that both prototype systems did not differ from the ALICE as to energy cost.

Table 4. Oxygen consumption relative to body mass (ml/kg/min), mean (SD)

	Fighting Load	Approach Load	Sustainment Load
MOLLE	17.4[a] (1.74)	18.6[b] (1.96)	21.0[c] (2.56)
MLS	17.4[a] (1.99)	18.7[b] (2.04)	20.7[c] (2.92)
ALICE*	17.4 (1.25)	18.0 (1.36)	20.2 (2.04)

Values superscripted with different letters are significantly ($p<0.05$) different.
*From a previous experiment (unpublished) using a different group of volunteers.

TIMED TESTS

Table 5 shows that, while there were significant differences in time required to carry the fighting, approach, and sustainment loads at maximal speed over two miles, there was no difference between the time required to carry the same load using the MLS versus MOLLE. The results for the ALICE from a previous study are shown for reference purposes, but the shorter times do not indicate that the ALICE is superior to the MLS and MOLLE. As mentioned before, the volunteers in that study were at an exceptionally high level of aerobic physical fitness and esprit de corps, which accounts for the difference in performance.

Table 5. Time (min) to cover two miles on foot, mean (SD)

	Fighting Load	Approach Load	Sustainment Load
MOLLE	21.01[a] (2.03)	25.58[b] (2.38)	29.40[c] (1.97)
MLS	21.30[a] (1.78)	25.26[b] (1.84)	29.63[c] (2.35)
ALICE*	19.47 (2.18)	21.64 (2.75)	25.325 (2.79)

Values superscripted with different letters are significantly ($p<0.05$) different.
*From a previous experiment (unpublished) using a different group of volunteers.

Table 6 shows that, while there were significant differences in time required to get prone and return to standing between the fighting and approach loads, there was no difference between the time required when carrying the same load using the MLS versus MOLLE. While the results for the ALICE were obtained on a different group of volunteers, it is apparent that both prototype systems did not differ from the ALICE as to time required to get prone and return to standing.

Table 6. Time (s) to get prone and return to standing, mean (SD)

	Fighting Load	Approach Load
MOLLE	2.42[c] (0.34)	3.15[b] (0.49)
MLS	2.44[c] (0.40)	3.04[b] (0.52)
ALICE*	2.49 (0.29)	3.00 (0.29)

Time without carrying a load: 2.10[a] (0.28)
Values superscripted with different letters are significantly ($p<0.05$) different.
*From a previous experiment (unpublished) using a different group of volunteers.

The MLS quick-release system did not work properly. The first few volunteers were not able to release the pack from the vest/belt ensemble. Thus testing of the MLS for time to remove the pack and get prone was discontinued. The mechanism on the MLS often released from only the upper anchors of the pack, causing it to flop back while still attached to the belt. This placed the volunteers in a very awkward position that would make them vulnerable on the battlefield. Because of the problem with the MLS, Table 7 depicts the results only for the MOLLE and ALICE. It can be observed that the volunteers from the previous experiment were able to remove the ALICE pack considerably faster than the volunteers from the present experiment could remove the MOLLE. That appears to be because the volunteers using the ALICE pack quickly learned to thrust back the arms and shoulders and fall forward, allowing the pack to tumble down behind them. The volunteers with the MOLLE used the quick release straps by pulling on them before falling forward as the pack fell backwards. Fumbling for the straps sometimes caused delay. The larger standard deviations for the MOLLE indicate that time to remove the MOLLE pack varied more than the time to remove the ALICE, supporting the point that the quick-release straps were sometimes difficult to find on the MOLLE.

Table 7. Time (s) to remove pack and get prone, mean (SD)

	Approach Load	Sustainment Load
MOLLE	3.81 (1.43)	3.88 (1.63)
ALICE*	1.66 (0.35)	1.85 (0.55)

*From a previous experiment (unpublished) using a different group of volunteers.

Table 8 shows that the volunteers took significantly longer to traverse the obstacle course with the approach load than the fighting load. It must be noted that there were seven trials in which volunteers couldn't traverse the entire 12-foot length of the horizontal pipe. One of the volunteers couldn't negotiate the pipe under any of the four

conditions, suggesting insufficient strength for the task. Another failed with the MOLLE fighting load and the MLS approach load. A third volunteer failed only with the MLS fighting load. The fact that the latter two volunteers failed with fighting loads despite succeeding with approach loads using the same load-carriage system suggests that those volunteers probably possessed marginal strength for the task and happened to be more fatigued or just slip off during the particular trials on which they failed.

Rather than report the total course times for only those volunteers who successfully negotiated the pipe, the times in the table represent total time for the obstacle course not counting time for the pipe, which is reported separately in Table 12 below for those volunteers who successfully completed it. Course times with the fighting load were similar for both load-carriage systems. However, volunteers were significantly faster with the approach load using the MLS than they were with the MOLLE. The volunteers using the ALICE system in the previous experiment were faster with both the fighting and approach loads than the volunteers using the MLS and MOLLE in the present experiment. That is likely more attributable to their high level of physical fitness and esprit de corps than differences related to the load-carriage system.

Table 8. Time (s) to complete all obstacle course stations except the horizontal pipe, mean (SD)

	Fighting Load	Approach Load
MOLLE	35.32[a] (4.12)	45.30[c] (4.93)
MLS	36.06[a] (3.64)	42.66[b] (6.39)
ALICE*	32.24 (3.70)	39.06 (3.47)

Values superscripted with different letters are significantly ($p<0.05$) different.
*From a previous experiment (unpublished) using a different group of volunteers.

Tables 9 through 14 show the times for each segment of the obstacle course. Table 9 shows there was no difference between the MLS and MOLLE as to the time required to traverse the low hurdles, with either the fighting or approach load. The faster times for the ALICE volunteers attests to their athleticism, because it doesn't seem that differences between the packs could have accounted for that large a difference in time.

Table 9. Time (s) to traverse obstacle course hurdles, mean (SD)

	Fighting Load	Approach Load
MOLLE	4.53^{a} (0.73)	4.99^{b} (0.78)
MLS	4.44^{a} (0.42)	5.04^{b} (0.96)
ALICE*	3.95 (0.41)	4.16 (0.29)

Values superscripted with different letters are significantly ($p<0.05$) different.
*From a previous experiment (unpublished) using a different group of volunteers.

Table 10 shows a lack of significant difference between the MLS and MOLLE for the zigzag course segment. Again, times for the ALICE volunteers on this segment were shorter.

Table 10. Time (s) to traverse obstacle course zigzag, mean (SD)

	Fighting Load	Approach Load
MOLLE	9.02^{a} (1.24)	9.60^{a} (0.65)
MLS	9.18^{a} (0.91)	9.13^{a} (1.59)
ALICE*	8.36 (0.64)	8.77 (0.80)

Values superscripted with different letters are significantly ($p<0.05$) different.
*From a previous experiment (unpublished) using a different group of volunteers.

Table 11 shows that, with the fighting load, times for the low-crawl did not differ significantly between the MLS and MOLLE. However, with the approach load, the volunteers took significantly longer when using the MOLLE than when using the MLS. This is likely due to a difference in the pack shape. The MLS was 8" shorter from top to bottom than the MOLLE, and 3" less front-to-back. The taller MOLLE had a tendency to press against the back of the soldier's helmet when he dove under the low-crawl obstacle. Also, the 3" greater front-to-rear pack thickness made the MOLLE more likely to rub against the top of the low-crawl station. On this course segment, the volunteers using the ALICE system to carry the approach load did not travel faster than the volunteers using the MLS. Their greater athleticism was likely negated by the relatively large front-to-back dimension of the ALICE.

Table 11. Time (s) to complete obstacle course low-crawl, mean (SD)

	Fighting Load	Approach Load
MOLLE	9.29[a] (1.49)	15.63[c] (2.84)
MLS	9.78[a] (1.49)	13.77[b] (2.94)
ALICE*	8.41 (1.91)	13.59 (2.26)

Values superscripted with different letters are significantly (p<0.05) different.
*From a previous experiment (unpublished) using a different group of volunteers.

As mentioned previously, there were seven failures to traverse the horizontal pipe completely. Four of the failures are attributed to one volunteer who could not negotiate the pipe under any system/load condition. Two of the failures are accounted for by another volunteer who failed with the MLS approach load and the MOLLE fighting load. The last failure was experienced by a third volunteer with the MLS fighting load. Table 12 shows that there was no significant difference between the MLS and MOLLE as to the time taken to negotiate the horizontal shimmy pipe, using either the fighting or approach load, although there was a nonsignificant trend for the MOLLE to be slower with the approach load. Statistical power was reduced when the volunteers who failed to traverse the pipe were removed from the analysis; a full complement of subjects may have produced a significant difference between approach load times.

Table 12. Time (s) to traverse obstacle course horizontal pipe, mean (SD)

	Fighting Load	Approach Load
MOLLE	15.70[a] (3.46)	25.33[b] (7.37)
MLS	15.20[a] (3.14)	22.76[b] (7.51)
ALICE*	13.51 (3.72)	18.73 (3.58)

Values superscripted with different letters are significantly (p<0.05) different.
Means do not include times for incomplete pipe traversals.
*From a previous experiment (unpublished) using a different group of volunteers.

Table 13 indicates that there was no difference between the MLS or MOLLE as to traversal time for the 1.37 meter high wall, either with the fighting or approach load.

Table 13. Time (s) to traverse obstacle course 1.37 meter high wall, mean (SD)

	Fighting Load	Approach Load
MOLLE	6.08[a] (1.45)	7.75[b] (1.60)
MLS	6.31[a] (1.11)	7.59[b] (1.79)
ALICE*	5.65 (0.98)	6.25 (1.01)

Values superscripted with different letters are significantly ($p<0.05$) different.
*From a previous experiment (unpublished) using a different group of volunteers.

Table 14 shows that there was no difference between the MLS or MOLLE as to time taken for the 28.5 m straight run, either with the fighting or approach load. Again, the volunteers using the ALICE were faster with both loads than the volunteers in the present study, attesting to their physical prowess rather than to differences in the pack.

Table 14. Time (s) to complete obstacle course 28.5 meter straight run, mean (SD)

	Fighting Load	Approach Load
MOLLE	6.41[a] (0.42)	7.33[b] (0.61)
MLS	6.34[a] (0.52)	7.13[b] (0.63)
ALICE*	5.87 (0.39)	6.29 (0.43)

Values superscripted with different letters are significantly ($p<0.05$) different.
*From a previous experiment (unpublished) using a different group of volunteers.

Table 15 shows that the differences in time taken to hit the ground, roll three times, and aim the rifle did not differ significantly between test conditions. The BDU condition showed a trend towards faster times. The time for the ALICE volunteers was nonsignificantly longer, which is especially notable since they were faster on other tests. It suggests that the ALICE is slower than the MLS and MOLLE for this type of maneuver, probably because it stands off the user's back and has a relatively large front-back dimension.

Table 15. Time (s) to get prone and roll three times, mean (SD)

	BDU	MOLLE Fighting Load	MLS Fighting Load	ALICE Fighting Load*
Time (seconds)	4.06 [a] (0.22)	4.48 [a] (0.39)	4.33 [a] (0.36)	4.77 (0.55)

Values superscripted with different letters are significantly (p<0.05) different.
*From a previous experiment (unpublished) using a different group of volunteers.

WEAPONS SKILLS

It should be noted that for the grenade throw results in Table 16, a lower number for distance from the target center is more desirable. It can be seen that there were no significant differences among any of the conditions for any of the grenade throw variables. However, volunteers throwing the grenade in BDU hit closer to the target and had a higher target hit percentage than when they carried either of the fighting loads. That makes sense in that the fighting vest has to be at least somewhat restrictive. The MLS condition appeared to have a small, nonsignificant advantage over the other pack systems. On this test the volunteers using the ALICE appeared to show poorer performance. Throwing is very technique-specific and is not much affected by general physical conditioning. The best throwers seemed to be the volunteers who reported having played baseball or softball.

Table 16. 35 meter grenade throw score, mean (SD)

	No Load	MOLLE Fighting Load	MLS Fighting Load	ALICE Fighting Load*
Distance from target center (inches)	98.24 [a] (42.0)	122.39 [a] (46.6)	113.42 [a] (34.3)	138.63 (90.8)
Percentage on target	96% [a] (8.8)	84% [a] (13.3)	87% [a] (33.2)	78% (37.6)

Values superscripted with different letters are significantly (p<0.05) different.
*From a previous experiment (unpublished) using a different group of volunteers.

Shooting accuracy differed across equipment conditions, with DCM, SGT, and % HITS all showing significant effects at $p \leq 0.05$ (Table 17). Differences in accuracy also were seen between shooting positions, DCM ($p \leq 0.0001$; Prone: 5.9 ± 1.6 mm versus Standing: 7.5 ± 1.3 mm), SGT ($p \leq 0.0001$; Prone: 80.9 ± 47.6 mm^2 versus Standing: 180.4 ± 64.9 mm^2), and % HITS ($p \leq 0.01$; Prone: 95.3 ± 7.0% versus Standing: 87.3 ± 14.0%). Sighting time differed significantly ($p \leq 0.02$) across the three equipment conditions, but did not differ between shooting positions. Shooting means and standard deviations by equipment condition and shooting position are shown in Table 18. No significant interaction effects were found between shooting position and equipment condition.

Table 17. Shooting scores (mean+SD) in BDU, and MLS and MOLLE fighting loads

	BDU	MLS	MOLLE
DCM	7.3^{a} (1.6)	6.4^{b} (1.5)	6.6^{b} (1.2)
SGT	152.2^{a} (60.1)	115.0^{b} (55.4)	$125.0^{a,b}$ (53.0)
% Hits	87^{a} (15.0)	93^{b} (10.0)	94^{b} (7.0)
STIME	7.4^{a} (2.4)	$7.0^{a,b}$ (2.8)	6.5^{b} (2.2)

Key Abbreviations:
DCM = distance from center of mass (mm).
SGT = shot group tightness (mm^2).
% Hits = percentage of targets hit.
STIME = sighting time (sec).
Values superscripted with different letters are significantly ($p<0.05$) different.

Table 18. Prone and standing shooting scores (mean$\pm$SD) in BDU and with the fighting loads

PRONE	BDU	MLS	MOLLE
DCM	6.5 (2.1)	5.3 (1.3)	6.0 (5.3)
SGT	87.7 (62.1)	71.3 (43.1)	84.0 (37.7)
% Hits	92.0 (13.2)	99.0 (3.2)	95.0 (5.3)
STIME	6.7 (2.5)	6.2 (2.9)	6.1 (2.5)
STANDING	**BDU**	**MLS**	**MOLLE**
DCM	8.0 (1.2)	7.4 (1.6)	7.2 (1.1)
SGT	216.7 (58.6)	158.6 (67.8)	165.9 (68.3)
% Hits	82.0 (16.2)	87.0 (17.0)	93.0 (9.5)
STIME	8.0 (2.2)	7.8 (2.7)	6.8 (1.8)

Key Abbreviations:
DCM = distance from center of mass (mm)
SGT = shot group tightness (mm^2)
% Hits = percentage of targets hit
STIME = sighting time (sec)

Subjective comments obtained from the volunteers (n=10) are listed in Table 19. These comments focused strictly on the use of the various equipment ensembles while shooting.

Table 19. Subjective comments on shooting

Comment	No. of vols.
All three systems (BDU, MLS, and MOLLE) are fine for shooting.	8
The MOLLE provides more support for shooting than does the MLS	7
The MLS is easier to shoot in than the MOLLE because you have more freedom of movement in the shoulder area of the body armor.	5
Overall, the MLS is more cumbersome than the MOLLE.	4
The MOLLE was more bulky and restricted shooting.	1

COMFORT

Table 20 shows that, as to frequency of complaints concerning the shoulder, the MOLLE and MLS were similar for the fighting load, while the MOLLE elicited considerably fewer complaints than the MLS with the approach load, and somewhat fewer complaints than the MLS with the sustainment load. Frequency of complaints for the MLS did not differ much between the approach and sustainment loads.

Table 20. Shoulder complaint frequency as a percentage of maximum possible responses*

	Fighting Load	Approach Load	Sustainment Load
MOLLE	16.7%	12.5%	27.1%
MLS	18.8%	31.3%	33.3%

* These percentages were obtained by totaling the number of subjects' responses that indicated some level of discomfort in the shoulder region and dividing this total by the maximum possible number of responses.

Table 21 shows that, as to the severity of complaints concerning the shoulder, the MOLLE and MLS didn't differ much for the fighting load, while with the approach load, the MOLLE elicited lower severity of shoulder discomfort than the MLS, although the difference was not statistically significant. The sustainment load did not produce any notable difference between the load-carriage systems in severity of discomfort.

Table 21. Shoulder pain/discomfort as a percentage of maximum possible score*

	Fighting Load	Approach Load	Sustainment Load
MOLLE	0.87% [a,b]	0.61% [a]	1.82% [b,c]
MLS	0.78% [a,b]	1.39% [a,b,c]	2.00% [c]

Values superscripted with different letters are significantly ($p<0.05$) different.
*These percentages were obtained by taking a weighted score for degree of discomfort for each body area that make up the shoulder region and dividing by the maximum possible score that could have been achieved.

Table 22 shows that, as to frequency of complaints concerning the hips, the MOLLE and MLS were similar for the fighting load, while the MOLLE elicited considerably fewer complaints than the MLS with the approach load. However, the MLS elicited somewhat fewer complaints than did the MOLLE for the sustainment load. It is interesting to note that frequency of hip complaints for the MLS did not differ at all among the different loads. For the MOLLE, the approach load elicited the fewest hip complaints.

Table 22. Hip complaint frequency as a percentage of maximum possible responses*

	Fighting Load	Approach Load	Sustainment Load
MOLLE	21.9%	15.6%	31.3%
MLS	25.0%	25.0%	25.0%

*These percentages were obtained by totaling the number of subjects' responses that indicated some level of discomfort in the hip region and dividing this total by the maximum possible number of responses.

Table 23 shows that, as to the severity of complaints concerning the hips, the MOLLE and MLS didn't differ significantly, even though the mean percentage of discomfort of the MLS with the approach load was more than twice that of the MOLLE. The sustainment load did not produce any notable difference between the load-carriage systems in severity of hip discomfort.

Table 23. Hip pain/discomfort as a percentage of maximum possible score*

	Fighting Load	Approach Load	Sustainment Load
MOLLE	2.73% [a]	0.98% [a]	3.52% [a]
MLS	2.73% [a]	2.15% [a]	3.13% [a]

Values superscripted with different letters are significantly ($p<0.05$) different.
*These percentages were obtained by taking a weighted score for degree of discomfort for the body areas that make up the hip region and dividing by the maximum possible score that could have been achieved.

The shoulders and hips are the main contact points of any framed backpack. Table 24 compares the load-carriage systems and loads as to complaint frequencies for all body areas excluding the shoulders and hips; many of these were likely due to indirect effects. It can be seen that complaint frequencies for these body areas did not differ to a notable degree between load-carriage systems.

Table 24. All other body areas complaint frequency as a percentage of maximum possible responses*

	Fighting Load	Approach Load	Sustainment Load
MOLLE	8.0%	6.2%	12.5%
MLS	8.0%	9.8%	14.3%

* These percentages were obtained by totaling the number of subjects' responses that indicated some level of discomfort in the shoulder region and dividing this total by the maximum possible number of responses.

As to severity of complaints for all body areas excluding the shoulders and hips, Table 25 shows that there was virtually no difference between load-carriage systems for the fighting load, while the MOLLE produced lower mean severity scores for the approach and sustainment loads than the MLS, though the differences did not reach statistical significance.

Table 25. All other body areas pain/discomfort as a percentage of maximum possible score*

	Fighting Load	Approach Load	Sustainment Load
MOLLE	0.239%[a,b]	0.159%[a]	0.335%[a,b]
MLS	0.207%[a,b]	0.255%[a,b]	0.446%[b]

Values superscripted with different letters are significantly ($p<0.05$) different.
*These percentages were obtained by taking a weighted score for degree of discomfort for each body area that make up areas other than the hip and shoulder region and dividing by the maximum possible score that could have been achieved.

Table 26 indicates that, as to frequency of total body complaints, the MOLLE and MLS were similar for the fighting load, while the MOLLE elicited considerably fewer complaints than the MLS for the approach load. The two load-carriage systems produced similar complaint frequencies for the sustainment load. Again, frequency of complaints for the MLS did not differ much between the approach and sustainment loads, while the MOLLE showed a much lower complaint frequency for the approach than for the sustainment load.

Table 26. Total body complaint frequency as a percentage of maximum possible responses*

	Fighting Load	Approach Load	Sustainment Load
MOLLE	12.5%	9.4%	19.3%
MLS	13.5%	17.7%	20.8%

* These percentages were obtained by totaling the number of subjects' responses that indicated some level of discomfort throughout the entire body and dividing this total by the maximum possible number of responses.

As to the severity of total body pain and discomfort, Table 27 shows that the two load-carriage systems produced similar severity scores with the fighting and sustainment loads. However, the MOLLE produced a lower severity score with the approach load, though the difference did not reach statistical significance.

Table 27. Total body pain/discomfort as a percentage of maximum possible score*

	Fighting Load	Approach Load	Sustainment Load
MOLLE	0.195% [a,b]	0.119% [a]	0.326% [b,c]
MLS	0.195% [a,b]	0.233% [a,b]	0.364% [c]

Values superscripted with different letters are significantly ($p<0.05$) different.
* These percentages were obtained by taking a weighted score for degree of discomfort for the entire body and dividing by the maximum possible score that could have been achieved.

BIOMECHANICS

Table 28 shows a trend for lateral foot contact forces averaged over the stride to be higher with the MLS than the MOLLE, suggesting more lateral movement of the MLS than the MOLLE. Table 29 shows a very similar relationship for peak lateral force. For both average and peak lateral force, the difference between load-carriage systems was significant only for the approach load.

Table 28. Lateral force (N) averaged over stride, mean (SD)

	Fighting Load	Approach Load	Sustainment Load
MOLLE	1.98 [a,b,c] (1.22)	1.71 [a] (0.88)	1.82 [a,b] (1.24)
MLS	2.27 [c] (1.13)	2.26 [c] (1.69)	2.16 [b,c] (1.63)

Values superscripted with different letters are significantly ($p<0.05$) different.

Table 29. Peak heel-strike lateral force (N), mean (SD)

	Fighting Load	Approach Load	Sustainment Load
MOLLE	37.3 [a,b] (21.3)	34.9 [a] (16.4)	34.9 [a] (22.1)
MLS	40.6 [b] (18.2)	42.0 [b] (26.9)	39.1 [a,b] (25.1)

Values superscripted with different letters are significantly ($p<0.05$) different.

Table 30 indicates that for the fighting load, the load center of mass was significantly lower for the MOLLE than the MLS. However, with both the approach and sustainment loads, the center of mass of the MOLLE was higher than for the MLS. A higher pack center of mass is usually associated with a more upright walking posture, closer to that characteristic of unloaded walking. The difference in center of mass vertical position can be attributed almost completely to the pack bag shape and location on the frame,

since all packs were loaded to place the center of mass at the center of the pack volume.

Table 30. Vertical distance (m) from pack center of mass to body center of mass, averaged over stride, mean (SD)

	Fighting Load	Approach Load	Sustainment Load
MOLLE	0.158[e] (0.022)	0.312[b] (0.026)	0.332[a] (0.019)
MLS	0.234[d] (0.014)	0.244[c] (0.013)	0.248[c] (0.031)

Values superscripted with different letters are significantly ($p<0.05$) different.
There was a significant ($p<0.05$) pack type by load interaction.
Positive distance indicates the pack center of mass is above the body center of mass.

The within-trial standard deviation of the sagittal-plane *horizontal* distance from the pack center of mass to mid-shoulder was used as a measure of the *front-back* pack movement relative to the soldier carrying the pack. Table 31 shows that there was very little of such movement with either pack. Standard deviations were in the range of one cm. With the fighting load, there was significantly more movement for the MOLLE than for the MLS, indicating greater looseness or flexibility of the fighting vest.

Table 31. Within-trial standard deviation of sagittal-plane horizontal distance (m) from pack center of mass to mid-shoulder, mean (SD)

	Fighting Load	Approach Load	Sustainment Load
MOLLE	0.013[a] (0.006)	0.009[c,d] (0.004)	0.009[c,d] (0.005)
MLS	0.011[b] (0.005)	0.010[b,c] (0.005)	0.007[d] (0.003)

Values superscripted with different letters are significantly ($p<0.05$) different.

To measure the *up-down* pack movement relative to the soldier carrying the pack, the within-trial standard deviation of the *vertical* distance from the pack center of mass to mid-shoulder was calculated. There were significant effects of both pack-type and load. As Table 32 shows, the sustainment load was associated with more vertical pack movement than were the fighting and approach loads, and for the sustainment load, there was significantly more vertical pack movement with the MOLLE than with the MLS, even though the magnitude of the difference was small.

Table 32. Within-trial standard deviation of vertical distance (m) from pack center of mass to mid-shoulder, mean (SD)

	Fighting Load	Approach Load	Sustain Load
MOLLE	0.007[a] (0.003)	0.007[a] (0.002)	0.009[c] (0.003)
ADL	0.006[a] (0.002)	0.006[a] (0.002)	0.008[b] (0.003)

Values superscripted with different letters are significantly ($p<0.05$) different.

It is interesting to observe many significant differences between system/load conditions for peak heel-strike vertical ground reaction force, as shown in Table 33. As expected, the heel-strike force increased with the load carried. As to system comparisons, while the load-carriage systems did not differ for the fighting load, the MOLLE produced significant 3-4% greater heel-strike forces than the MLS for the approach and sustainment loads. In general, lower impact forces are considered more desirable and less injurious.

Table 33. Peak heel-strike vertical ground reaction force (N), mean (SD)

	Fighting Load	Approach Load	Sustainment Load
MOLLE	1089.6[a] (149.8)	1197.5[c] (146.0)	1352.6[e] (142.0)
MLS	1081.8[a] (147.0)	1159.0[b] (141.8)	1300.3[d] (146.25.5)

Values superscripted with different letters are significantly ($p<0.05$) different.

As seen in Table 34, a similar pattern emerged for the push-off vertical ground reaction force as for the peak heel-strike vertical force. The forces increased significantly with the load carried. While the load-carriage systems did not differentially affect this variable for the fighting load, the MOLLE produced significant 3-5% greater push-off vertical forces than the MLS for both the approach and sustainment loads.

Table 34. Peak push-off vertical ground reaction force (N), mean (SD)

	Fighting Load	Approach Load	Sustainment Load
MOLLE	1039.0[a] (138.6)	1201.2[c] (139.3)	1358.3[e] (134.8)
MLS	1027.7[a] (109.7)	1165.2[b] (149.4)	1296.2[d] (149.2)

Values superscripted with different letters are significantly ($p<0.05$) different.

Rear knee angle is defined as the sagittal-plane angle formed behind the knee by the upper and lower legs. The maximum rear knee angle indicates how straight the leg becomes during walking. Table 35 indicates that with the fighting load, there was no difference in maximum rear knee angle between the load-carriage systems. However, with both the approach and sustainment loads, volunteers using the MLS didn't quite straighten their legs while walking, but they did when they used the MOLLE; this statistically significant difference was about 1.5 degrees. The straighter leg characteristic of the MOLLE indicates that the volunteers using that system deviated less from a normal walking gait then when they used the MLS.

Table 35. Maximum rear knee angle (deg), mean (SD)

	Fighting Load	Approach Load	Sustainment Load
MOLLE	181.9^{c} (8.73)	181.0^{c} (7.31)	180.0^{b} (7.82)
MLS	182.1^{c} (8.21)	179.2^{a,b} (6.57)	178.8^{a} (8.16)

Values superscripted with different letters are significantly ($p<0.05$) different.

Table 36 shows that knee range of motion dropped as the load increased. The reduced knee motion serves to enhance stability during load-carriage and reduces body joint torque relative to what it would be if a normal unloaded walking stride were maintained. Load-carriage system had no significant effect.

Table 36. Knee range of motion (deg), mean (SD)

	Fighting Load	Approach Load	Sustainment Load
MOLLE	72.50^{c} (6.78)	71.11^{b} (6.54)	69.95^{a,b} (5.72)
MLS	73.59^{c} (6.68)	70.73^{a,b} (5.87)	69.55^{a} (6.51)

Values superscripted with different letters are significantly ($p<0.05$) different.

The sagittal plane ventral trunk/thigh angle is defined as the sagittal-plane angle formed in front of the body between the trunk and upper leg. The minimum value of that angle is an indicator of how far forward the trunk was inclined during load-carriage. Table 37 shows that the volunteers inclined the trunk forward about one degree more with the MLS than the MOLLE with the fighting load, and about two degrees more with the approach and sustainment loads. The differences for all but the fighting load were statistically significant. The higher center of mass of the MOLLE pack, as indicated in Table 30, is likely a major factor in the difference. The lower center of mass of the MLS would require the volunteer to incline the trunk forward more in order to get the center of mass of the pack more directly over the base of support. A more upright walking

posture is considered desirable because it is closer to the normal unloaded walking posture and is usually more efficient.

Table 37. Minimum sagittal plane ventral trunk/thigh angle (deg), mean (SD)

	Fighting Load	Approach Load	Sustainment Load
MOLLE	148.5[e] (6.49)	140.4[d] (6.33)	134.9[b] (7.79)
MLS	147.6[e] (6.81)	138.4[c] (5.84)	133.2[a] (7.03)

Values superscripted with different letters are significantly ($p<0.05$) different.

The maximum sagittal plane ventral trunk/thigh angle is an indicator of how upright the trunk became during load-carriage. Table 38 shows that the volunteers tended to become more upright with the MOLLE than with the MLS, but the difference was significant only with the approach load. Again, the higher center of mass of the MOLLE pack is a likely cause, allowing a more desirable upright walking posture. An added advantage of a soldier walking more upright is the increased likelihood of noticing potential threats.

Table 38. Maximum sagittal plane ventral trunk/thigh angle (deg), mean (SD)

	Fighting Load	Approach Load	Sustainment Load
MOLLE	197.6[d] (6.98)	193.4[c] (7.46)	190.9[a,b] (6.99)
MLS	197.3[d] (8.43)	191.9[b] (7.12)	190.5[a] (7.58)

Values superscripted with different letters are significantly ($p<0.05$) different.

The range of the sagittal plane trunk angle is largely a measure of the front-back sway of the trunk during walking. Table 39 shows that the sway tended to increase as the load increased. The two pack systems differed significantly in sway for the fighting and sustainment loads, for which the front-back sway was respectively 14% and 39% greater with the MLS than with the MOLLE. Less sway would be considered more desirable because it represents less perturbation from normal gait and would seem less likely to cause fatigue or loss of balance.

Table 39. Sagittal plane trunk angular range (deg), mean (SD)

	Fighting Load	Approach Load	Sustainment Load
MOLLE	2.17[a] (0.76)	2.60[b,c] (0.61)	2.79[c] (0.82)
MLS	2.47[b] (0.81)	2.69[b,c] (0.58)	3.87[d] (0.54)

Values superscripted with different letters are significantly ($p<0.05$) different.
There was a significant ($p<0.05$) pack type by load interaction.The vertical range of the subject's center of mass provides an indication of the degree to which the subject bobs up and down while walking. Table 40 shows that the only significant load-carriage system effect was with the approach load, for which vertical bobbing was greater for the MLS than for the MOLLE. The difference was due to raising the body higher during the stride, rather than to lowering it more. Table 41 shows that the low point of the body's center of mass did not differ among load-carriage systems. However, as the load increased, the body reached a significantly lower bottom point during the stride. Thus it can be said that as the load increased, the center of mass traveled through about the same vertical distance, with the high and low points lowered by about the same amount.

Table 40. Vertical range (m) of subject center of mass, mean (SD)

	Fighting Load	Approach Load	Sustainment Load
MOLLE	0.060[a,b] (0.008)	0.059[a] (0.007)	0.063[c] (0.009)
MLS	0.061[b,c] (0.007)	0.063[c] (0.008)	0.062[b,c] (0.009)

Values superscripted with different letters are significantly ($p<0.05$) different.
There was a significant ($p<0.05$) pack type by load interaction.

Table 41. Minimum body center of mass height, mean (SD)

	Fighting Load	Approach Load	Sustainment Load
MOLLE	0.958[c] (0.033)	0.955[b,c] (0.028)	0.945[a] (0.028)
MLS	0.957[c] (0.034)	0.952[b] (0.034)	0.946[a] (0.031)

Values superscripted with different letters are significantly ($p<0.05$) different.

During walking, the foot normally strikes the ground following the swing phase of the leg, so that the foot exerts a forward force on the ground. In turn, the ground exerts an equal and opposite force on the foot which acts to decelerate the body's forward

motion; this is called the braking force. Greater braking force would be expected to be associated with greater fatigue and injury risk. It increases movement and friction between the foot and shoe, which heightens the likelihood of blisters. Table 42 shows that the braking force increased significantly as the load increased, for both load-carriage systems. That is expected, since it takes a greater force to decelerate a greater mass. Yet there were no significant differences between the load-carriage systems as to braking force.

Table 42. Braking force averaged over entire stride, mean (SD)

	Fighting Load	Approach Load	Sustainment Load
MOLLE	32.61[c] (7.98)	35.63[b] (6.50)	41.51[a] (7.16)
MLS	32.12[c] (6.02)	36.34[b] (5.91)	41.67[a] (7.59)

Values superscripted with different letters are significantly ($p<0.05$) different.

A similar pattern emerged for peak heel-strike braking force as for braking force averaged over entire stride. Table 43 shows that heel-strike peak braking force increased significantly as the load increased, for both load-carriage systems, with no significant differences between the load-carriage systems.

Table 43. Peak heel-strike braking force, mean (SD)

	Fighting Load	Approach Load	Sustainment Load
MOLLE	207.96[c] (44.30)	227.46[b] (39.49)	271.12[a] (48.49)
MLS	203.71[c] (39.03)	227.15[b] (37.34)	267.79[a] (53.09)

Values superscripted with different letters are significantly ($p<0.05$) different.

Average pressure under the shoulder straps increased significantly with the load, as seen in Table 44. Comparing load-carriage systems, the difference was significant only for the sustainment load, under which the MOLLE produced 75% higher pressures than the MLS. The mean pressure was 75% higher for the MOLLE approach load as well, but due to the large standard deviations, the difference was not statistically significant. *Peak* pressure did not show any notable effects.

Table 44. Average pressure under shoulder straps, psi, mean (SD)

	Fighting Load	Approach Load	Sustainment Load
MOLLE	0.017[a] (0.027)	0.191[c,d] (0.189)	0.445[e] (0.384)
MLS	0.044[a,b] (0.097)	0.109[b,c] (0.187)	0.255[d] (0.246)

Values superscripted with different letters are significantly ($p<0.05$) different.

Table 45 shows that there was only one significant effect on average pressure at mid-back: the pressure was significantly higher for the MLS sustainment load than for all other conditions (three times the pressure of the MOLLE sustainment load, and five-to-six times the pressure of either approach load). However, as seen in Table 46, the MLS did not produce significantly higher *peak* pressures at mid-back than did the MOLLE although, for the approach load, the mean for peak pressure was 74% higher for the MLS than for the MOLLE. In fact, peak pressure with the MLS sustainment load was 10% lower than with the MOLLE.

Table 45. Average pressure (psi) under backpack belt at mid-back, mean (SD)

	Fighting Load	Approach Load	Sustainment Load
MOLLE	0.044[a] (0.085)	0.029[a] (0.057)	0.061[a] (0.082)
MLS	0.003[a] (0.007)	0.036[a] (0.053)	0.183[b] (0.305)

Values superscripted with different letters are significantly ($p<0.05$) different.

Table 46. Peak pressure (psi) under backpack belt at mid-back, mean (SD)

	Fighting Load	Approach Load	Sustainment Load
MOLLE	2.52[a] (4.20)	1.98[a] (2.27)	3.25[a] (1.68)
MLS	1.75[a] (3.78)	3.44[a] (4.58)	2.94[b] (2.88)

Values superscripted with different letters are significantly ($p<0.05$) different.

DURABILITY OF THE MOLLE

During the experiment, one of the prototype MOLLE frames developed a vertical crack near the bottom of the frame where it tapered into a fitting designed to snap into a receptacle on the back of the belt. MOLLE systems have since been used for other experiments and more of them have developed cracks in the same location. These

cracks appear to have been caused by torsion on the frame due to trunk rotation during load-carriage. It must be noted that the test frames were made using prototype casting equipment which, according to the manufacturer, could have made the frames less durable than if full-production casting equipment had been used. This seems to have been verified via a field trial conducted subsequent to the conclusion of the experiment described herein. In the trial, the MOLLE was tested by the U.S. Army 75th Ranger Regiment; the 1st Battalion of the 24th Infantry, Ft. Lewis, WA; and the 3rd Battalion, 2nd Marines, Camp LeJeune, NC. Testing took place from November 1998 through February 1999. Over 200 MOLLE systems were tested during field operations that included several road marches 10 to 30 miles long with reported weights of 50 to 90 pounds, Airborne Operations, and rough handling such as being thrown onto and off of vehicles while loaded. At the conclusion of the field trial only one damaged frame was reported. Thus properly manufactured MOLLE frames appear durable enough for military use.

DISCUSSION

ENERGY COST

In a previous experiment (8), we observed that pack center of mass location can affect the energy cost of load-carriage, with a center of mass high and close to the body associated with a lower energy cost than a center of mass lower and further away from the body. Although the MOLLE pack had a higher center of mass than the MLS and ALICE, the difference was apparently not enough to cause a notable difference in energy cost among the pack systems. A possible explanation is that, in the previous experiment, the loaded pack weighed close to 75 pounds, and the center of mass was varied through a relatively large vertical range. In the experiment described in this report, the pack itself only weighed about 30 pounds for the approach load and 60 pounds for that sustainment load, with the remaining 40 pounds distributed over the body. Thus, the center of mass of the pack itself did not have as much impact on the center of mass of the entire load as in the previous study. The difference in pack center of mass location between the MOLLE and MLS was in the range of only 7-8 cm.

PHYSICAL PERFORMANCE

The lack of difference between the MOLLE and MLS as to 2-mile load-carriage speed reflects the lack of difference in energy cost of load-carriage between the packs. With the same energy cost, the packs would be expected to yield similar 2-mile run times, because ability to run two miles is largely limited by aerobic capacity (6). A similar energy cost should thus yield a similar run time.

The lack of difference between the MOLLE and MLS as to the time needed to drop to the ground and return to a standing position is also likely related to the lack of a major difference in center of mass location. While a lower pack center of mass location is associated with a greater energy cost, it is also associated with a faster time to drop

and return to standing, because the lower load location reduces the moment of inertia and resistive torque about the feet. The difference in center of mass location between the two packs was apparently not great enough to affect time needed to drop to the ground and return to a standing position.

The MOLLE proved to have an effective pack bag quick-release mechanism that allowed the soldier to drop the bag while retaining the fighting load. The MLS quick-release mechanism did not function. Several times the pack bag released only partially, leaving with the bag hanging from the soldier in an awkward position. This would clearly impair the agility of a soldier and place him at risk of becoming a casualty on the battlefield. It must be noted that the fastest way to remove a pack remains to slip directly out of the shoulder straps, as the volunteers did in the ALICE pack study. Using the current MOLLE quick-release mechanism proved slower than slipping out of the ALICE shoulder straps because of the time needed to find the quick-release strap tabs. If the tabs could be more prominently located, time to remove the pack might be considerably reduced.

On the obstacle course, volunteers with the approach load were faster using the MLS than the MOLLE. The major difference was on the low-crawl obstacle. The MOLLE made it more difficult to crawl because, due to its height, it tended to hit against the soldier's helmet as he dove to the ground, pushing the helmet forward over the eyes. Also the greater front-back thickness of the MOLLE required a lower crawl, which is slower and more strenuous.

Rifle shooting with either the MLS or MOLLE fighting load was significantly better than with BDU only. It appears likely that the added weight may have damped breathing and body sway movements, two factors that normally detract from shooting accuracy (7). While volunteers shooting in the MLS produced slightly tighter shot groups than in the MOLLE, they took an extra 0.5 sec to do so; neither difference was statistically significant. From the subjective comments, the two systems appeared comparable for shooting and were viewed favorably by most of the volunteers. The comments and the performance results suggest that differences were based on personal preferences and minor individual shooting variations. While some soldiers mentioned that there was more freedom of movement in the shoulder area with the MLS, this did not translate into faster times to sight and shoot the target. The prone position was more stable for shooting, yielding shots 21% closer to the center of the target and having 55% tighter shot groups. These findings are similar to two previous studies (one published [11] and the other unpublished) showing similar results between shooting positions.

COMFORT

The MOLLE appeared more comfortable around the shoulder than the MLS, eliciting considerably fewer complaints for the approach load, and somewhat fewer complaints for the sustainment loads. The severity of complaints about the shoulder was also considerably lower for the MOLLE than the MLS under the approach load, but not the sustainment load. The MOLLE was also better than the MLS as to frequency

and severity of complaints about the hip under the approach load, but not the sustainment load. Frequency and severity of total body complaints were also lower for the MOLLE than the MLS with the approach load. It is quite clear that the MOLLE is at its best under the approach load; that is, about 70 lb of total load of which the loaded pack bag accounts for about 30 lb It is possible that, if needed, the pack can be modified to improve its advantage at a heavier load by stiffening the frame and increasing the density or amount of the padding.

BIOMECHANICS

The center of mass of the MOLLE pack was 7-8 cm higher than that of the MLS. However, since the pack was only 43% of the total clothing and equipment load for the approach condition, and 50% of the total load for the sustainment condition, the difference in the vertical location of the center of mass of the total load probably differed by only 3-4 cm, apparently not enough to affect the energy cost of load-carriage or the ability to traverse the obstacle course wall.

Lower impact forces of the foot on the ground are generally considered less likely to produce injury, not only of the foot, but of the legs and back. It is not completely clear why the MOLLE brought about higher heel-strike forces than the MLS. One possibility is the straighter leg associated with carrying the MOLLE; a straight leg doesn't damp peak force as much as a bent leg. Kinoshita (9) demonstrated an increase in both hip and knee flexion as load increased, a postural change hypothesized to aid in shock absorption. A similar trend was observed in this study, with the leg becoming less straight as load increased. Despite this pattern with both load-carriage systems, the subjects walking with the MOLLE evidenced straighter legs overall than when they walked with the MLS.

Another possible reason for the higher foot impact forces with the MOLLE is the pack's higher center of mass, which might have increased the forward rotary inertia of the body, necessitating a higher heel-strike force to provide a counteracting torque to return the body to upright. Also, the MOLLE could have been stiffer than the MLS, causing more rapid deceleration of the pack at foot impact and thus greater forces on the body.

Forward trunk flexion has been shown to increase with load (5, 9) as a means of keeping the load-plus-body center of mass over the base of support. The further behind the soldier's back that the pack center of mass is located, the more the soldier must incline the trunk forward to bring the combined center of mass over his feet. In the present study increases in trunk flexion with load were also demonstrated. However, the MLS produced greater amounts of trunk flexion than did the MOLLE. The higher center of mass of the MOLLE probably accounts for the difference. The lower center of mass of the MLS requires the volunteer to incline the trunk forward more in order to get the center of mass of the pack more directly over the feet.

A more upright walking posture during load-carriage is considered desirable because it is closer to the normal unloaded walking posture and is usually more efficient. The MOLLE appears to have provided the advantage over the MLS of maintaining a loaded walking posture closer to a normal unloaded walking posture. The more normal walking posture associated with the MOLLE included more complete straightening of the knees, a more upright trunk, and less front-back trunk sway. The more upright posture that the MOLLE allows should minimize fatigue over a long hike and allow the soldier to be more observant of potential threats.

Holewijn (4) suggested that skin contact pressures greater than 1.45 psi result in local changes in subcutaneous circulation and recommended that pack contact pressures not exceed this limit in order to avoid skin injury. With both the MOLLE and MLS, both shoulder strap and rear waist-belt average pressures were well below this recommended upper limit. However, peak pressures exceeded the limit. Since there were no reported injuries due to contact pressure, it seems likely that transiently high contact pressures do not pose an injury risk. It is interesting that the MOLLE produced fewer and less severe shoulder complaints than the MLS even though it produced higher average pressures about the shoulder. Apparently, average pressure does not correspond closely to discomfort and pain.

For the sustainment load, the MOLLE showed a higher average pressure under the pack straps than did the MLS, despite the fact that there was no significant difference between the packs as to complaints about the shoulder with that load. As to average pressure under the pack belt at mid-back, the MLS was particularly poor under the sustainment load.

While the MOLLE has generally shown to be a very good system and a prime candidate for the standard Army load-carriage system, there was a problem of poor frame durability, which was evidenced as frame cracking after repeated heavy use. However, extensive field testing conducted subsequent to the conclusion of the experiment described herein suggests that the problem has been solved via the implementation of full-production casting methods.

CONCLUSIONS

- The MOLLE and MLS did not differ as to energy cost of load-carriage.
- The MOLLE and MLS did not differ as to the speed at which loads could be carried.
- The MOLLE and MLS did not differ as to the speed at which a walking soldier could get prone and return to a standing position.
- The MOLLE quick-release mechanism functioned, while the MLS was inoperable. However, the MOLLE quick-release system could be improved to make it easier for the soldier to find and reach. Slipping out of the pack straps still appears to be faster than using the quick-release mechanism.

- Volunteers were faster on the obstacle course with the MLS than the MOLLE, which is largely attributable to problems with the MOLLE on the low-crawl obstacle, including a larger front-back dimension and a tendency for the top of the pack to hit the soldier in the back of the helmet. Subsequent to the conclusion of the experiment described herein, this problem was addressed by reducing the length of the MOLLE frame.
- There was a trend for the MOLLE to be associated with slower times on the horizontal pipe. This may be due to a center of mass closer to the head which placed more weight on the arms and hands. However, the higher center of mass of the MOLLE didn't make for better times in crossing the wall obstacle, as might have been expected.
- Under the fighting load, there was a nonsignificant trend for better grenade-throwing with the MLS than the MOLLE.
- The MOLLE and MLS did not differ as to the speed at which a walking soldier could get prone, roll laterally three times and aim his weapon.
- The MOLLE elicited fewer shoulder complaints than did the MLS, especially with the approach load.
- With the approach load, the MOLLE elicited less severe shoulder complaints than did the MLS; severity of complaints was similar between the systems for the other loads.
- Frequency of hip complaints was similar between the systems with the fighting load, higher for the MLS with the approach load, and higher for the MOLLE with the sustainment load.
- Severity of hip complaints was similar between the systems with the fighting and sustainment loads, but higher for the MLS with the approach load.
- Frequency and severity of complaints about all body areas other than the shoulders and hips tended to be higher for the MLS than the MOLLE.
- Frequency and severity of total body complaints was similar between the systems with the fighting and sustainment loads, but about twice as high for the MLS than the MOLLE with the approach load.
- Peak and average lateral forces of the feet on the ground were higher with the MLS than the MOLLE. Higher forces are considered less desirable.
- The center of mass of the MOLLE is relatively high in relation to the soldier's body, compared to the MLS. This allows a more upright walking gait, but may impair performance on the low-crawl because of contact between the pack and helmet and because of increased weight on the arms when the body is horizontal.
- The horizontal movement between the pack and soldier's body was in the one cm range for all conditions, indicating good stability, except for the MOLLE fighting load, which was in the three cm range, indicating excessive looseness. The MOLLE vest and body armor appeared too big around the waist for most of the soldiers, allowing movement relative to the body; with the pack on, excessive movement was eliminated. However, the excessively large waist and stiffness of the vest made it very difficult to tighten the pack belt enough to transfer much load to the hips. Since a great majority of combat soldiers are physically fit, the waist of the body armor could likely be made several inches smaller without being too tight.

- The MOLLE produced greater heel-strike and toe push-off forces than did the MLS, which are considered less desirable. This may have resulted from the more upright walking posture exhibited with the MOLLE, and more complete straightening of the knee.
- The more upright walking posture exhibited with the MOLLE than the MLS is considered more desirable for minimizing fatigue and allowing the soldier to be more observant.
- The MOLLE produced less trunk front-back sway than did the MLS. This is considered desirable for minimization of fatigue.
- Vertical bobbing of the body was similar between both systems for the fighting and sustainment loads. However, with the approach load, the MOLLE produced less vertical bobbing than did the MLS. This is considered desirable for minimization of fatigue.
- The MOLLE and MLS did not differ as to peak or average braking force during load-carriage.
- The MOLLE and MLS did not differ as to knee range of motion.
- With both the approach and sustainment loads, the MOLLE placed considerably greater average pressure on the shoulder straps than did the MLS.
- Average pressure under the backpack belt was higher for the MLS than the MOLLE. However, peak pressure under the sustainment load was greater for the MOLLE than the MLS.
- The MOLLE and MLS did not differ as to effect on marksmanship.
- The soldiers had more positive and less negative comments about the MOLLE than about the MLS.
- The problem of lack of durability of the MOLLE frame appears to have been adequately addressed via the implementation of full-production casting methods.

RECOMMENDATIONS

The MOLLE is more fully developed and functional than the MLS. If a choice were to be made between the two systems, the MOLLE would clearly be more worthy of development for use as the standard Army load-carriage system. The MOLLE quick-release system functioned as intended, while that of the MLS didn't, leaving soldiers potentially vulnerable with partially detached backpacks hanging from their bodies. Comfort ratings were generally higher for the MOLLE than for the MLS. The soldiers had more positive and fewer negative comments about the MOLLE than about the MLS. The MOLLE was associated with a more upright walking posture, likely to minimize fatigue over a long hike and allowing the soldier to be more vigilant in regard to potential threats. Additionally, pockets on the MOLLE fighting vest made it easy to secure items and remove them when needed, while the MLS pockets were difficult to use and didn't hold items securely. Sometimes pockets on the MLS had to be taped closed to prevent items from falling out during the tests.

Despite its apparent superiority over the MLS, the MOLLE could still be improved. The following are some recommendations in this regard:

- The pack straps probably should be widened or more fully padded to distribute the load over a greater skin area, because the MOLLE produced higher average pressure under the pack straps than the MLS for the sustainment load, even though reports of discomfort weren't greater.
- The quick-release tabs should protrude more towards the front, rather than laying against the sides of the chest, so that the soldier doesn't have to fumble for them. Stiffer material for the quick-release tabs or inserts made of wire or plastic might be used to keep the tabs easily accessible.
- A possible alternative to the pull-tab quick-release mechanism would be a redesigned set of shoulder straps that would allow the soldier to throw his arms down and backwards to let the pack drop backwards.
- A reduced pack height and front-back dimension would make the MOLLE more effective for crawling under obstacles. The reduced pack height would also make it easier to traverse the horizontal pipe, because less weight would be on the hands. The reduction in pack volume that would result from reducing both pack height and front-back depth could be made up by making the pack wider. While the pack center of mass would become lower, it should not be enough to negatively impact energy cost or physical performance. A lowered center of mass for the MOLLE might also serve to reduce the higher heel-strike forces it was associated with.
- The MOLLE pack should be modified to provide as much advantage for the sustainment load as it had for the approach load. This might involve beefing up the frame and padding. The frame is strong, but its flexibility may not provide an optimal degree of support under a very heavy load.
- The MOLLE fighting vest seems to be excessively loose for most soldiers, causing undue movement, and should probably be redesigned to fit closer to the body.
- The body armor designed to work with the MOLLE does not fit the body snugly enough, making it difficult to fit the pack properly. With the armor and fighting vest in place, the pack waist-belt cannot be cinched down tightly enough to distribute much of the load to the hips. A major design change may be considered, in which the pack belt itself is armored with Kevlar and the vest is shorter so that it doesn't have to be under the pack belt. That would allow the waist-belt to be snugly cinched so that a good portion of the load could be supported on the hips rather than on the shoulders. At the very least, the waist of the armor should be reduced by several inches.

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APPENDIX A

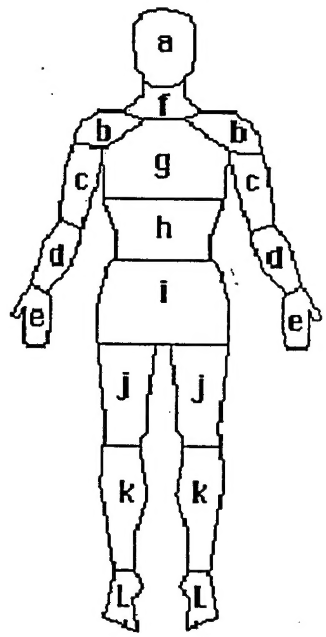
Physical Discomfort Questionnaire

Subject #: ______ Date: _________ Test Condition: ____________

INSTRUCTIONS: Rate the degree of SORENESS, PAIN, or DISCOMFORT that you are currently feeling for Body Parts A through L. Do so for the FRONT and the BACK of the body.

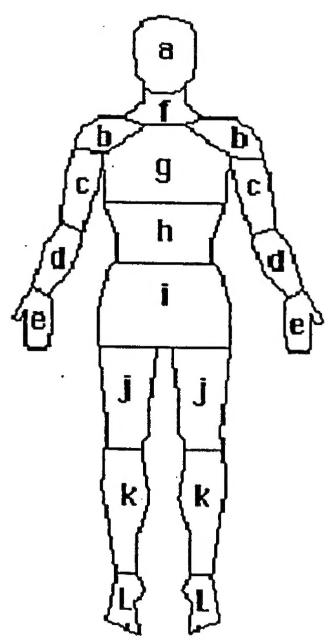
FRONT of Body

	a	b	c	d	e	f	g	h	i	j	k	L
NONE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
SLIGHT	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
MODERATE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
SEVERE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
EXTREME	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐



BACK of Body

	a	b	c	d	e	f	g	h	i	j	k	L
NONE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
SLIGHT	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
MODERATE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
SEVERE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
EXTREME	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐



APPENDIX B

RECORD OF ENVIRONMENTAL CONSIDERATION
U.S. Army Research Institute of Environmental Medicine
Natick, MA 01760-5007

DATE: 4 February 1997

Protocol Number and Title: "Physiological, biomechanical, and maximal performance comparisons of soldiers carrying light, medium, and heavy loads using the Land Warrior and the All Purpose, Lightweight, Individual Load Carrying Equipment (ALICE) Systems"

Performing Element(s): Military Performance Division, U.S. Army Research Institute of Environmental Medicine, Natick, MA

Anticipated Start Date: 16 March 1997 **Projected End Date:** 16 April 1997

Description of Proposed Action: The research protocol identified above and fully described in the attached documentation consists of scientific research efforts in both laboratory and field setting.

Determination: It has been determined that the action qualifies for Categorical Exclusion(s) numbers A-11 and A-19 as described in Appendix A, AR 200-2, and no extraordinary circumstances exist as defined in paragraph 4-3, AR 200-2 because all physiological (laboratory) operations will be conducted within enclosed facilities where airborne emissions, waterborne effluent, external radiation levels, outdoor noise, and solid bulk waste disposal practices will be in compliance with existing Federal, State, and local laws and regulations. The field tests will be conducted with military and/or civilian personnel at USARIEM and USANRDEC, and/or military perseonnel on TDY status, and/or civilians living within Natick, MA area; existing living facilities will be used and the activities to be performed will have no significant impact on the environment.

Signed: ______________________________ Date: ______________
Chief, Military Performance Division

Concur/Nonconcur: ______________________________ Date: ______________
USARIEM Environmental Coordinator

Coordination: ______________________________ Date: ______________
Installation Environmental Coordinator